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Contents

LIST OF ABBREVIATIONS

acronym	**Explanation**
LFI	Low Frequency Instrument
HFI	High Frequency Instrument
IDPs	Interplanetary Dust Particles
MOB	Mobile Object
SSB	Solar System Baricenter
SSO	Solar System Object
TBC	To Be Confirmed
TBD	To Be Defined
TOD	Time Ordered Data
TODs	Plural of TOD
TOI	Time Ordered Information
TODs	Plural of TOI
ZLE	Zodiacal Light Emission
DZLE	ZLE code from DIRBE WebSite
KZLE	Ken code for ZLE
HFIZLE	HFI residuals for ZLE
MZLE	Maris code for ZLE or My ZLE
ApJZLE	Paper ZLE model of Kelsall on ApJ
AXVZLE	Paper ZLE model of Kelsall on Archiv

1 Applicable and Reference Documents

Applicable Documents

[AD-0] Maris M.,2011 *ZLE Maps for the Planck Mission III: Simulated Flight Maps* Planck/LFI Int.Rep.: PL-LFI-OAT-TN-071, Issue 1.0, 2011, Jan 31$^{\rm th}$

[AD-0] Maris M., Burigana C., Fogliani S.,2005 *Simulation aspects on the zle modelling in the Planck mission* Internal Report IASF-BO 429/2005

[AD-0] Maris, M., 2001, PLANCK*/LFI - FS_ZOD: A Simulator of the Zodiacal Light Emission for the* PLANCK *Mission*, 2001, Planck/LFI Int.Rep.: PL-LFI-OAT-TN-023, Issue 1.0

[AD-0] Maris, M., Fogliani, S., Burigana, C., 2004, *How to use the Zodiacal Light Emission Maps for* PLANCK , Planck/LFI Int.Rep.: PL-LFI-OAT-TN-031, Issue 1.0, 2004, Dec 31$^{\rm th}$

[AD-0] *Maps of ZLE Contribution for the* PLANCK *Mission* Maris M., Burigana C., Fogliani S., 2004 Dec 31$^{\rm st}$, PL-LFI-OAT-TN-032

[AD-0] *ZLE: Spectral Dependence and K correction* Maris M., Burigana C., Fogliani S., 2004, PL-LFI-OAT-TN-033

[AD-0] *Static Maps of Zodiacal Light Emission for the Planck Mission* Maris M., Burigana C., 2006 Oct. 7$^{\rm th}$, PL-LFI-OAT-TN-055 (number erroneously assigned to another report, to be renumbered)

[AD-0] *ZLE: Spectral Dependence and K correction* Maris M., Burigana C., 2007 Dec 3rd, PL-LFI-OAT-TN-045

[AD-0] *Attitude History File ICD* Tuttlebee, M.,J. 2009 July 24$^{\rm th}$, Issue 2.6 or higher, DMS Document ID : PT-PMOC-FD-ICD-2110-OPS-GFT; PTGS Document ID: PGS-ICD-006

[AD-0] *ZLE Maps for the Planck Mission III: Validation of ZODY models and codes* Maris., M., et al., 2011 Sep 05$^{\rm th}$, Issue 0.4 or higher,

[AD-0] *ZLE Maps for the Planck Mission IV: Fitting of Geometrical Parameters* Maris., M., et al., 2011 Sep 05$^{\rm th}$, Issue 0.4 or higher,

Reference Documents

[RD-0] Kelsall, T., Weiland, J.T., Franz, B.A., Reach, W.T., Arendt, R.G., et al., 1998, ApJ, 508, 44 (also astro-ph/9806250)

[RD-0] Fixsen, D.J., & Dwek, E., 2002, Ap.J., 578, 1009

[RD-0] Wheelock, S.L., Gautier, T.N., Chillemi, J., Kester, D., McCallon, H., et al., 1994, IRAS Sky Survey Atlas Explanatory Supplement, JPL Pubbl. 94-11

[RD-0] Maris, M., Burigana, C., Fogliani, S., 2005, *Zodiacal Light Emission in the* PLANCK *mission*, A&A, 2006, 452, 685-700.

[RD-0] Maris, M., Burigana, C., Gruppuso, A., Finelli, F., Diego, J.M., 2011 *Large-scale traces of Solar system cold dust on cosmic microwave background anisotropies*, MNRAS,2011,415,2546

[RD-0] The JPL-Horizons service and its documentation is availlable at the site http://ssd.jpl.nasa.gov/?horizons

[RD-0] Nesvorny et al.(2010) COMETARY ORIGIN OF THE ZODIACAL CLOUD AND CARBONACEOUS MICROMETEORITES. IMPLICATIONS FOR HOT DEBRIS DISKS ApJ, 713:816836, 2010 April 20

[RD-0] HFI Collaboration, (2011), Planck Early Results: The High Frequency Instrument data processing.
A&A in press.

2 Scope of the document

This report is a followup of [AD-0] [AD-0] [AD-0] [AD-0], [AD-0], [AD-0] [AD-0] [?] [?] and [?].

The main scipe of this document is to gives prediction of the level of contamination expected from ZLE to the C_ℓ in cosmological channels.

2.1 Limits of Applicability

The results in this issue 2011 Oct 01, 0.0 of the document are subject to the following limitations:

1. Only Planck data are used to constrain the model parameters.
2. DX7 maps;
3. Differential fitting;
4. Cloud and Bands are generated keeping the parameter in K98.
5. Circumsolar ring and Trailling blob are not considered.

3 Estimate of Zody spectra at HFI frequencies

The Zody spectra at HFI frequencies are estimated on the difference maps of Survey2 - Survey1, by minimizing the following χ^2

$$\chi^2 = \sum_{i\mathrm{pix}\in\mathrm{AllowedPixels}} \frac{\left(\tilde{E}^{\mathrm{C}}_f \Delta Z^{\mathrm{C}}_{f,ij,i\mathrm{pix}} + \tilde{E}^{\mathrm{B}}_f \Delta Z^{\mathrm{B}} f, ij, i\mathrm{pix} \tilde{E}^{\mathrm{sl}}_f \Delta SL_{B,ij,i\mathrm{pix}} - \Delta T_{f,ij,i\mathrm{pix}}\right)^2}{\sigma^2_{\Delta T,f,ij}} \quad (1)$$

the sum is computer over a list of allowed pixels, i.e. pixels not masked either becouse they are not visited in one of the two surveys or their survey–to–survey variation is too large, or show other anomalies (see Sect. A.3).

The model of Cloud variation $\Delta Z^{\mathrm{C}} f, ij, i\mathrm{pix}$, and Bands variation $\Delta Z^{\mathrm{B}}_{f,ij,i\mathrm{pix}}$ are computed by using the K98 model and simulating the scanning strategy for each frequency channell and survey, the $\Delta SL_{B,ij,i\mathrm{pix}}$ is a sidelobes map template normalized to have $\max(|\Delta SL_{B,ij,i\mathrm{pix}}|) = 1$. The free parameters are $\tilde{E}^{\mathrm{C}}_f$, $\tilde{E}^{\mathrm{B}}_f$ and $\tilde{E}^{\mathrm{sl}}_f$.

The error bars for $\tilde{E}^{\mathrm{C}}_f$, $\tilde{E}^{\mathrm{B}}_f$ for each frequency are derived from MonteCarlo, assuming the error is dominated by white noise with variance map given by $\sigma^2_{\Delta T,ij,i\mathrm{pix}'}$.

Note that in general Cloud and Bands variations are expressed in MJy/sr while $\Delta T_{f,ij}$ are expressed in K_{CMB}. So either the model has to be converted to K_{CMB} or the data has to be converted to MJy/sr, in this analysis the conversion have been not applied. So the $\tilde{E}^{\mathrm{C}}_f$, $\tilde{E}^{\mathrm{B}}_f$ already include any conversion factor, as well as they include the effect of colour correction, but in this way they can not be compared directly with E^{C}_f, E^{B}_f extrapolated from K98. However, since we are interested in spectra this is not a problem.

The $\tilde{E}^{\mathrm{C}}_f$ and $\tilde{E}^{\mathrm{B}}_f$ so derived are then used to produce extimated Zodiacal Light maps defined as

$$T_{\mathrm{zody},f} = \tilde{E}^{\mathrm{C}}_f Z^{\mathrm{C}}_f + \tilde{E}^{\mathrm{B}}_f Z^{\mathrm{B}}_f; \quad (2)$$

with $Z_f^{\rm C}$ and $Z_f^{\rm B}$ the full sky templates for Cloud and Bands.

A set of statistics can be drawn from those maps in particular relevant for us are:

$T_{0,{\rm zody},f}$: the baseline (zero point) of the zody map.

$$T_{0,{\rm zody},f} = \min(T_{{\rm zody},f}) \tag{3}$$

$T_{peak,{\rm zody},f}$: the peak signal on the zody map.

$$T_{peak,{\rm zody},f} = \max(T_{{\rm zody},f}) \tag{4}$$

$T_{peak,{\rm zody},f}$: the 4π sky averaged Zody map.

$$\langle T_{{\rm zody},f} \rangle = \frac{1}{4\pi} \int_{4\pi} T_{{\rm zody},f}(\hat{\mathbf{\Omega}})\, d\hat{\mathbf{\Omega}} \tag{5}$$

note that this is the quantity given by Fixsen and Dwek (2002) as a FIRAS spectrum for ZODY.

$C_\ell^{\rm Z}$: the `ANAFAST` C_ℓ `for the zody map.`

It is important to note how the zero point $T_{0,{\rm zody},f}$ is badly predicted by the K98 model, so the estimated profiles could have a systematic error on $T_{0,{\rm zody},f}$ much larger than the quoted statystical error. Indeed it is lilkely believedthat K98 model underestimated $T_{0,{\rm zody},f}$, but however this is not a problem in this analysis, since we are interested in the peaak–to–peak variation of the signal over the map:

$$\delta_{\rm pp} T_{{\rm zody},f} = T_{peak,{\rm zody},f} - T_{0,{\rm zody},f} \tag{6}$$

Fig. 1 gives the spectral dependence of $E_f^{\rm C}$ and $E_f^{\rm B}$. The $E_f^{\rm C}$ does not scale down has ν^2 as expected from Fixsen and Dwek (2002) if confirmed this would mean that the smooth cloud at 100 GHz shall be even ten thousands stronger than expected from FIRAS. This is point worth of reanalysis. The distribution of $E_f^{\rm B}$ is about flat, even if it suggests an increase at the lowest frequencies.

Uncertainties comes from the colour correction to be applied at the theoretical model. If Bands have flat $E_f^{\rm B}$ spectral dependence their power should scale more or less as ν^2 and the colour correction should be some percent. The Cloud was expected to scale down as ν^4 introducing an about 10% colour correction. The horizontal lines shows the bandwidth of each frequency channel, as reovered from the latest RIIMO, and the amount of variation on $E_f^{\rm C}$ and $E_f^{\rm B}$ introducted by introducing or neglecting the largest possible colour correction. The differences are quite small.

Another possible systematic error comes from the effect of Side Lobes. The plot shows what happend removing from the model the sidelobes template (triangles) The bands are quite affected since sidelobes have a size and power comparable to bands. Indeed by masking the sidelobes where they are stronger most of the $E_f^{\rm B}$ systematic is removed (circles) [1].

Fig. 2 represents the spectra of Zody as derived from the current measures and analysis. Systematics could change the signal of some 20% and a better assesment would be an important topic for the next release of this report.

The signal below $\approx 260 GHz$ is dominated by the bands, indeed below 217 GHz the estimate of the cloud signal is not reliable.

[1]This is worth of deeper analysis in a future version of the report.

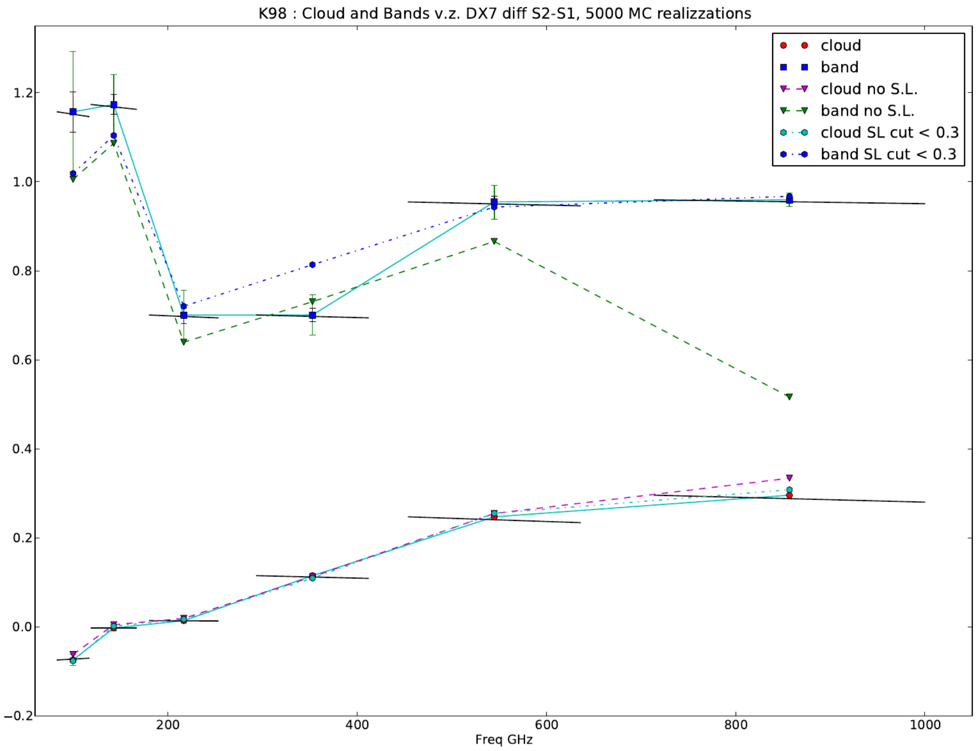

Figure 1: $E_f^{\rm B}$ and $E_f^{\rm C}$ for $K98$ Squares $E_f^{\rm C}$ and $E_f^{\rm B}$ from minimization of Eq. (1) with errorBars are drawn at 1 and 3 sigma. The fit is performed by taking the side lobes template as it is. The nearly horizontal bands represents the bandwidth, their vertical displacemente represents the uncertainty introduced by the color corrections. Triangles are cloud and band fitted forcing $E_f^{\rm sl} \equiv 0$, error bars are avoided for clarity. The circles are Cloud and Bands fitted after having cutted away the pixels in the sidelobes template above a threshold 0.3. It is interesting to note how at 100 GHz and 143 GHz the cloud is compatible with zero (a negative $E_f^{\rm C}$ or $E_f^{\rm B}$ would represent a subtraction of power).

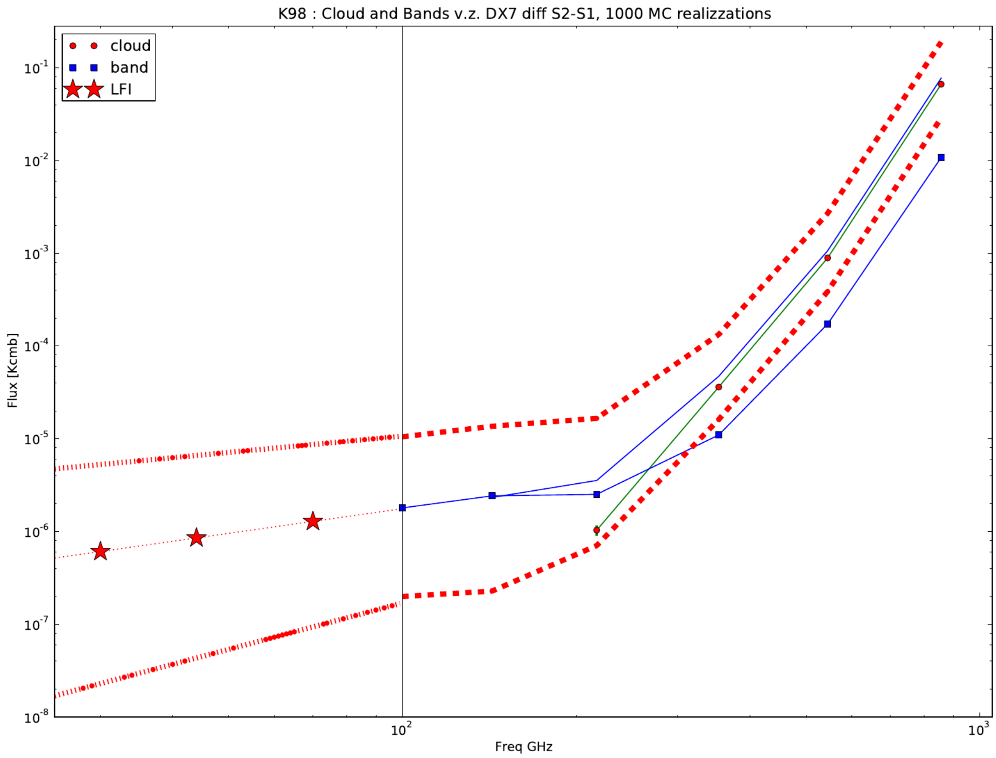

Figure 2: Sky averaged spectra in K_{CMB} of Zody and extrapolation at LFI Frequencies. The sky averaged signal for Cloud is denoted by circles, squares denotes the sky averaged signal for bands. Below 217 GHz the cloud signal is compatible with zero (the fit gives negative signal) so it can not be shown in this logarithmic plot. The line without symbols is the averaged sky signal, sum of Cloud and Bands. The two dashed red lines are $T_{0,\mathrm{zody},f}$ (bottom) and $T_{peak,\mathrm{zody},f}$ (top). The stars represents the extrapolation of sky aveaged signal at LFI frequencies.

Freq [GHz]	C_ℓ $[\mu K^2_{\rm CMB}]$ $\ell=1$	$\ell=2$	$\ell=3$	$\ell=4$	$\ell=5$
30	3.0e-06 ± 1.1e-06	1.3e+00 ± 2.6e-01	7.7e-04 ± 1.5e-04	5.1e-01 ± 9.9e-02	5.0e-04 ± 9.9e-05
44	6.9e-06 ± 1.8e-06	2.1e+00 ± 3.3e-01	1.1e-03 ± 1.7e-04	7.8e-01 ± 1.2e-01	6.6e-04 ± 1.0e-04
70	1.9e-05 ± 2.8e-06	3.9e+00 ± 4.0e-01	1.9e-03 ± 1.9e-04	1.3e+00 ± 1.3e-01	9.3e-04 ± 9.3e-05
100	5.3e-05 ± 4.0e-06	6.1e+00 ± 4.5e-01	2.6e-03 ± 1.9e-04	1.9e+00 ± 1.4e-01	1.1e-03 ± 8.1e-05
143	6.1e-05 ± 4.0e-06	1.0e+01 ± 4.7e-01	4.6e-03 ± 1.7e-04	3.2e+00 ± 1.2e-01	1.9e-03 ± 7.9e-05
217	3.0e-04 ± 4.9e-05	1.7e+01 ± 8.7e-01	5.9e-03 ± 2.8e-04	4.5e+00 ± 2.2e-01	2.0e-03 ± 1.1e-04
353	2.6e-01 ± 6.2e-03	1.4e+03 ± 2.8e+01	4.9e-01 ± 9.2e-03	2.5e+02 ± 5.7e+00	1.2e-01 ± 2.3e-03
545	1.5e+02 ± 1.4e+00	6.3e+05 ± 5.6e+03	2.4e+02 ± 1.9e+00	9.9e+04 ± 1.1e+03	6.4e+01 ± 5.5e-01
857	8.7e+05 ± 2.6e+03	3.2e+09 ± 1.0e+07	1.3e+06 ± 3.5e+03	4.8e+08 ± 1.9e+06	3.6e+05 ± 1.1e+03

Table 1: Estimated C_ℓ at HFI Frequencies and extrapolated ones at LFI frequencies. Errors includes just the statistical errors and are derived with MonteCarlos.

4 Predicted impact multipoles and extrapolation for LFI

Fig. 2 represents the spectra of Zody as derived from the current measures and analysis. Systematics could change the signal of some 20% and a better assesment would be an important topic for the next release of this report.

The extrapolated sky averaged value at 70 GHz is about 1.3 $\mu K_{\rm CMB}$, but peak value is about $7\mu K_{\rm CMB}$. Note that both the sky averaged values are affected by the zero point uncertainty, however since the minimum value is some $0.1\mu K_{\rm CMB}$ the peak–to-peak variation at 70 GHz would have to be $5 \div 7\mu K_{\rm CMB}$. Most of this signal has to be concentrated around the ecliptic.

The Survey to Survey differential variation is expected to be about 10% of peak–to–peak signal, or $\approx 0.7\mu K_{\rm CMB}$ likely outside the LFI capabilities at least working with just two surveys.

It has to be noted that in this analysis it have been neglects the resonant dust, (circumsolar ring plus Trailling blob), if it will behave as Bands, the signal could be even stronger.

In addition the possible contribution of the cold dust in the outer solar system (which can not be detected from analysis of differential data) could further enhance the signal.

Fig. 3 represents the expansion in multipoles of the Zody map at different frequencies. Multipoles at LFI frequencies are extrapolated from maps at the higher frequencies.

It is evidend how even multipoles are much more affected than the odd multipoles, a fact already pointed out in Maris etal 2011 [RD-0], more over most of the power is concentrated into the first 10 multipoles [2].

[2] This could be used to setup a filter to extract the total power profile.

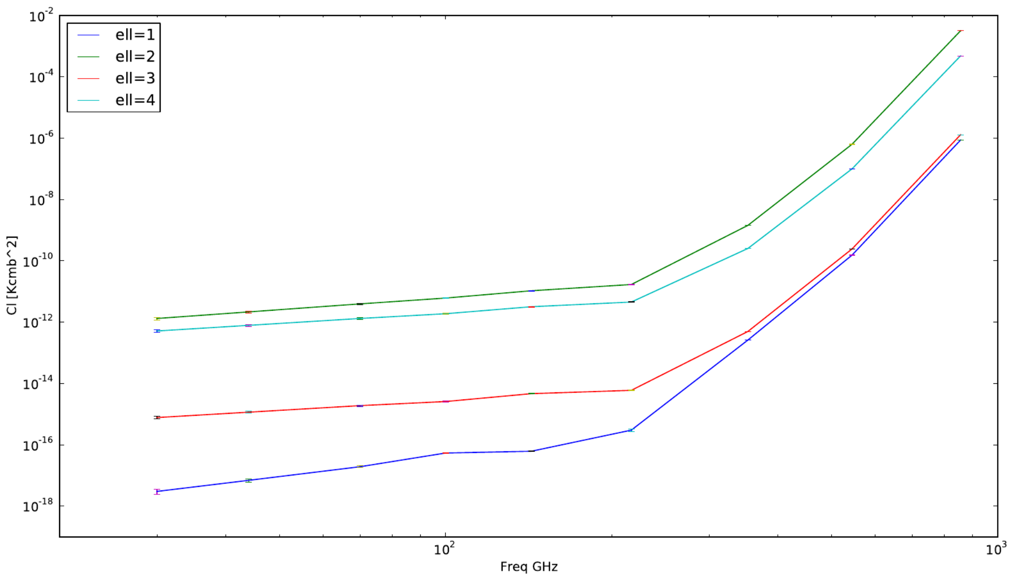

Figure 3: Sky averaged spectra in $K_{\rm CMB}$ of Zody and extrapolation at LFI Frequencies. The sky averaged signal for Cloud is denoted by circles, squares denotes the sky averaged signal for bands. Below 217 GHz the cloud signal is compatible with zero (the fit gives negative signal) so it can not be shown in this logarithmic plot. The line without symbols is the averaged sky signal, sum of Cloud and Bands. The two dashed red lines are $T_{0,{\rm zody},f}$ (bottom) and $T_{peak,{\rm zody},f}$ (top). The stars represents the extrapolation of sky aveaged signal at LFI frequencies.

A Technicalitis

In the following:

i_{pix} denotes a pixel number of a map

$X_{i\text{pix}}$ denotes a pixel of map X

T_f, i denotes a Temperature map for frequency channel f and survey i, it corresponds to the `I_Stokes` column of an exchange file.

$N_{\text{hits}f}, i$ denotes an Hits map for frequency channel f and survey i, it corresponds to the `Hits` column of an exchange file.

$\sigma^2_{T,f,i}$ denotes a covariance noise map for frequency channel f and survey i, it corresponds to the `I_cov` column of an exchange file.

Δ Prepending a Δ denotes a difference map (ex.: $\Delta T_{f,i}$).

A.1 Difference Maps

Difference maps of data are defined as follow:

$$\Delta T_{f,ij} = T_{f,j} - T_{f,j} \tag{7}$$

difference maps are defined only where the pixels of the input map are visited in the survey, i.e. where the corresponding hits map is not zero. Pixels not visited (i.e. those with 0 hits in one of the two maps are masked as NaN and not used).

The expected noise covariance for each pixeld of a difference map is

$$\sigma^2_{\Delta T,f,ij} = \sigma^2_{T,f,i} + \sigma^2_{T,f,j} \tag{8}$$

where $\sigma^2_{\Delta T,f,i}$ and $\sigma^2_{\Delta T,f,j}$ are the noise variances for the two maps.

A.2 Degrading Data Maps

Maps are degraded from their original $Nside = 2048$ or $N_{\text{side}} = 1024$.

The algorithm of downgrading an original map of given N_{side} downgraded to $N_{\text{side}}{}'$ is based on the idea of simulating the scan of rings drawn onto an $N_{\text{side}}{}'$ map.

So denoting with i'_{pix} a pixel of the target map and with $\{i_{\text{pix}}\}_{i\text{pix}'}$ the corresponding set of pixels in the original map which projects onto i'_{pix}

$$N_{\text{hits}\,i\text{pix}'} = \sum_{i\text{pix} \in \{i\text{pix}\}_{i\text{pix}'}} N_{\text{hits}\,i\text{pix}}; \tag{9}$$

$$T_{i\text{pix}'} = \frac{1}{N_{\text{hits}\,i\text{pix}'}} \sum_{i\text{pix} \in \{i\text{pix}\}_{i\text{pix}'}} N_{\text{hits}\,i\text{pix}} T_{i\text{pix}}; \tag{10}$$

$$\sigma^2_{T,i\text{pix}'} = \frac{1}{N_{\text{hits}}{}^2_{i\text{pix}'}} \sum_{i\text{pix} \in \{i\text{pix}\}_{i\text{pix}'}} N_{\text{hits}}{}^2_{i\text{pix}} \sigma^2_{T,i\text{pix}}; \tag{11}$$

A.3 Selecting pixels

The criteria for pixels selection on maps are the following:

1. Pixels are visited in both surveys;
2. The pixel does not project onto the Galaxy or does not have a too briliant source inside;
3. The survey–to–survey average does not exceed $2(f/857\text{GHz})^2$ MJy/sr;
4. The survey–to–survey variation does not exceed $2(f/857\text{GHz})^2$ MJy/sr;
5. The survey–to–survey variation of the sidelobes template does not exceed a given threshold (usually this cut is not applied).

The first two cuts removes the largest part of the bad pixels, while the last two cuts removes just a small fraction. The cut is calibrated at 857 GHz and a change of the threshold does not afffect much the result. Only the Side Lobes template cut affects in a sensible way the fitting.

A.4 Sidelobes Cut

To be written.